BAGLEY

Alternating Current Contact Maker for Precision Measurements

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ALTERNATING CURRENT CONTACT MAKER FOR PRECISION MEASUREMENTS

BY

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THESIS

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IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

GLEN DAVID BAGLEY

ENTITLED ALTERNATING CURRENT CONTACT MAKER

FOR PRECISION MEASUREMENTS.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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AN ALTERNATING CURRENT CONTACT-MAKER FOR PRECISION MEASUREMENTS.

I.

The function of this machine is to close an alternating current circuit at any predetermined point on the electromotive force wave. This is a necessary prerequisite for the study of alternating current transient phenomena as the value of the transient depends entirely upon the point at which the circuit is closed. Consider the case of a simple circiut containing resistance and inductance. The fundamental equation for such a circuit is,

$$e = ir + L \frac{di}{dt}$$

Consider the electromotive force to be a sine wave.

$$e = E \sin \omega t$$

Then $$e = ir + L \frac{di}{dt} = E \sin \omega t$$

(1) Dividing by L $$\frac{di}{dt} + \frac{r}{L} i = \frac{E}{L} \sin \omega t$$

This is a linear equation and may be integrated by the use of the integrating factor $\epsilon^{\int \frac{r}{L} dt}$

$$\frac{di}{dt} \epsilon^{\int \frac{r}{L} dt} + \frac{r}{L} i \epsilon^{\int \frac{r}{L} dt} = \frac{E}{L} \sin \omega t \, \epsilon^{\int \frac{r}{L} dt}$$

(2) $$di \, \epsilon^{\int \frac{rt}{L}} + \frac{r}{L} i \epsilon^{\int \frac{rt}{L}} dt = \frac{E}{L} \sin \omega t \, \epsilon^{\int \frac{rt}{L}} dt$$

The second term is of the form $d \epsilon^{u} = \epsilon^{u} du$

Therefore $\quad di\,\epsilon^{\frac{rt}{L}} + i\,d(\,\epsilon^{\frac{rt}{L}}\,) = \frac{E}{L}\sin\; t\,\epsilon^{\frac{rt}{L}}\;dt$

The left hand side is now in the form

$$d\,(xy) = y\,dx + x\,dy$$

$$d\,(\,i\,\epsilon^{\frac{rt}{L}}\,) = \frac{E}{L}\;\sin\omega t\;\;\epsilon^{\frac{rt}{L}}\;dt$$

$$i\,\epsilon^{\frac{rt}{L}} = \frac{E}{L}\int \sin\omega t\;\;\epsilon^{\frac{rt}{L}}\;dt + \;K$$

(3) $$i = \epsilon^{\frac{-rt}{L}}\;\frac{E}{L}\int \sin\omega\,t\;\;\epsilon^{\frac{rt}{L}}\;dt + K\;\epsilon^{\frac{-rt}{L}}$$

The term on the right hand side may be integrated by parts.

Let $u = \sin\omega t$ and $dv = \epsilon^{\frac{rt}{L}}\,dt$

$du = \omega\cos\omega t\;dt \qquad v = \frac{L}{r}\;\epsilon^{\frac{rt}{L}}$

Then $$\int \sin\omega\,t\;\;\epsilon^{\frac{rt}{L}}\;dt = \sin\omega t\;\frac{L}{r}\;\epsilon^{\frac{rt}{L}} - \int \frac{L}{r}\;\epsilon^{\frac{rt}{L}}\;\omega\cos\omega t\;dt$$

(4) $$= \sin\omega t\;\frac{L}{r}\;\epsilon^{\frac{rt}{L}} - \frac{L\,\omega}{r}\int \epsilon^{\frac{rt}{L}}\;\;\cos\omega t\;dt$$

Integrating by parts again

Let $u = \cos\omega t \qquad dv = \epsilon^{\frac{rt}{L}}\;dt$

$du = -\,\omega\sin\omega t\;dt \qquad v = \frac{L}{r}\;\epsilon^{\frac{rt}{L}}$

(5) $$\int \epsilon^{\frac{rt}{L}}\;\cos\omega t\;dt = \cos\omega\,t\;\frac{L}{r}\;\epsilon^{\frac{rt}{L}} + \int \frac{L}{r}\;\epsilon^{\frac{rt}{L}}\;\omega\sin\omega t\;dt$$

$$= \cos\omega t\;\frac{L}{r}\;\epsilon^{\frac{rt}{L}} + \frac{L\,\omega}{r}\int \epsilon^{\frac{rt}{L}}\;\;\sin\omega t\;dt$$

(6) Therefore from 4 $\quad \int \sin\omega t\;\;\epsilon^{\frac{rt}{L}}\;dt =$

$$\sin\omega t \; \frac{L}{r}\, \epsilon^{\frac{rt}{L}} - \frac{L\omega}{r}\left[\cos\omega t \; \frac{L}{r}\, \epsilon^{\frac{rt}{L}} + \frac{L\omega}{r}\int \epsilon^{\frac{rt}{L}} \sin\omega t \; dt \right.$$

$$= \sin\omega t \, \frac{L}{r}\, \epsilon^{\frac{rt}{L}} - \frac{\omega L^2}{r^2}\, \epsilon^{\frac{rt}{L}} \cos\omega t - \frac{L^2\omega^2}{r^2}\int \epsilon^{\frac{rt}{L}} \sin\omega t \; dt$$

$$(7) \quad \left(1 + \frac{L^2\omega^2}{r^2}\right)\left(\int \epsilon^{\frac{rt}{L}} \sin\omega t \; dt\right) = \sin\omega t \; \frac{L}{r}\, \epsilon^{\frac{rt}{L}} - \frac{\omega L^2}{r^2}\, \epsilon^{\frac{rt}{L}} \cos\omega t$$

Substituting in 3

$$i = \epsilon^{\frac{-rt}{L}} \frac{E}{L}\left[\frac{\sin\omega t \, \frac{L}{r}\, \epsilon^{\frac{rt}{L}} - \frac{\omega L^2}{r^2}\, \epsilon^{\frac{rt}{L}} \cos\omega t}{\frac{r^2 + L^2\omega^2}{r^2}}\right] + K\epsilon^{\frac{-rt}{L}}$$

$$= \frac{E}{L}\left[\frac{Lr\sin\omega t - \omega L^2\cos\omega t}{r^2 + L^2\omega^2}\right] + K\epsilon^{\frac{-rt}{L}}$$

$$= \frac{E}{r^2 + L^2\omega^2}\left[r\sin\omega t - \omega L\cos\omega t \right. + K\epsilon^{\frac{-rt}{L}}$$

$$= \frac{E}{z}\left[\frac{r}{z}\sin\omega t - \frac{x}{z}\cos\omega t\right] + K\epsilon^{\frac{-rt}{L}}$$

Let $\phi = \tan^{-1}\frac{x}{r}$

Then $\frac{r}{z} = \cos\phi$ and $\frac{x}{z} = \sin\phi$

$$i = \frac{E}{z}\left[\cos\phi\sin\omega t - \sin\phi\cos\omega t\right] + K\epsilon^{\frac{-rt}{L}}$$

$$= \frac{E}{z}\sin(\omega t - \phi) + K\epsilon^{\frac{-rt}{L}}$$

Let $\omega t = \theta$

Then $i = \frac{E}{z}\sin(\theta - \phi) + K\epsilon^{\frac{-rt}{L}}$

When $t = 0$; $i = 0$

$$K = -\frac{E}{z}\sin(\theta - \phi)$$

Then $i = \frac{E}{z} \sin(\theta - \phi)(1 - \epsilon^{\frac{-rt}{L}})$

This equation shows that the current which flows when a circuit is closed depends upon the time since it is a function of the angle . The equation also shows that the current gradually comes to the form of a sine wave as the time t increases in the term $\epsilon^{\frac{-rt}{L}}$ and causes it to approach zero. It was for the study and investigation of such phenomena as this that the contact maker was designed and constructed.

II.

A machine for closing the circuit as described above has been in existence in the Electrical Engineering Laboratory for some time. This machine consists of a rotating drum attached to the shaft of the generator and mounted on a separate base. The drum is made partly of brass and partly of fiber. The dividing line between these two is a helix which makes a single revolution around the cylinder. This helix is continued on the insulating portion of the drum by a rib of fiber which makes several turns around the drum. A copper brush sliding on a square rod carried on a rotating carriage is moved across the face of the drum by a spring. When this brush comes in contact with the fiber helix it is carried along between the turns and makes contact on the brass portion of the cylinder at the axial line which connects the ends of the single turn of the dividing line helix. The carriage which supports the brush may be rotated so that the contact may be made at any predetermined angle. From inspections and tests of this machine the following faults were discovered. The brush chattered as it made the contact on the brass cylinder as shown by oscillograms of several waves. This was due to friction on the fiber

helix, to the roughness of the drum and to insufficient tension on the brush spring and too much pressure on the spring which moves the brush across the cylinder. Several times in the tests the brush jumped over the helix. The drum was not perfectly balanced and this coupled with insufficient rigidity in the machine caused excessive chattering and vibration. The brush method of making contact proved rather unsatisfactory as the edge of the brush wore off by constantly rubbing on the cylinder. The means for angular adjustment was a disk with a hole drilled in it for each degree and a pin which fitted into these holes and locked the carriage. This method is not sufficiently accurate.

III

In the new machine the faults to be eliminated were vibration and chattering, friction between brush and cylinder, lack of rigidity and the inaccuracy of angular measurement. In order to stop the chattering, the shafts and bearing blocks of the new machine were made much more substantial and a heavy iron base was provided to increase the inertia of the machine and decrease the magnitude of the vibrations. These features are shown in Plates I, II, and III. The fiber rib was removed from the drum and the drum made smooth so that it could be turned up absolutely true. An auxiliary shaft L was provided, driven from the main shaft K by means of the gears, M and N, which by means of a thread cut on it and a movable nut O to which the contact roller P was attached moved the roller across the cylinder Q. This screw was of such a pitch that it moved the roller at exactly the same speed as that of the axial motion of a point on the dividing helix which made it impossible for the roller to make contact at any place on the helix except on the axial line connecting the two ends of the helix. By making the width of the

roller a little less than one half the length of this line, the whole width of the roller was made to come in contact at once, since the auxiliary shaft was driven by a two to one gear. The brush was replaced by a roller in order to make a smoother running contact, and a spring and catch was provided to support the roller out of contact with the drum when it was not in use. The roller is also less liable to be destroyed by arcing when closing circuits for considerable amounts of current. This roller is supported by a carriage R which slides on two circular rods, U and V, in a manner similar to that of a lathe carriage on its bed. These rods are supported by two heavy disks, S and T, carried on bearings concentric with the main shaft. These disks also carry the shaft which moves the carriage. Two other rods, W and X, connect these two disks in such a manner as to form a stiff frame-work for the carriage to slide on. These details are shown in Plates IV, V, and VI. The disks are capable of rotating and being clamped in any position by a set screw Y. A graduated circle is attached to one of the disks. This is read by means of a vernier attached to one of the bearing blocks. This is shown in Plate VII. The speed of the drum was determined upon as 1800 R. P. M. since at this speed with sixty cycle current, there are two cycles per revolution making one actual degree equal to two electrical degrees. If the speed were decreased the number of electrical degrees to one actual degree would be increased and the accuracy of measurement decreased. A set of change gears was provided so that the drum could be run at a constant speed, irrespective of the number of poles on the machine to which it was attached.

IV

Considerable difficulty was experienced in the construction of the machine because of the lack of tools for such small and accur-

ate work. In several instances special tools had to be constructed to do some part of the machining.

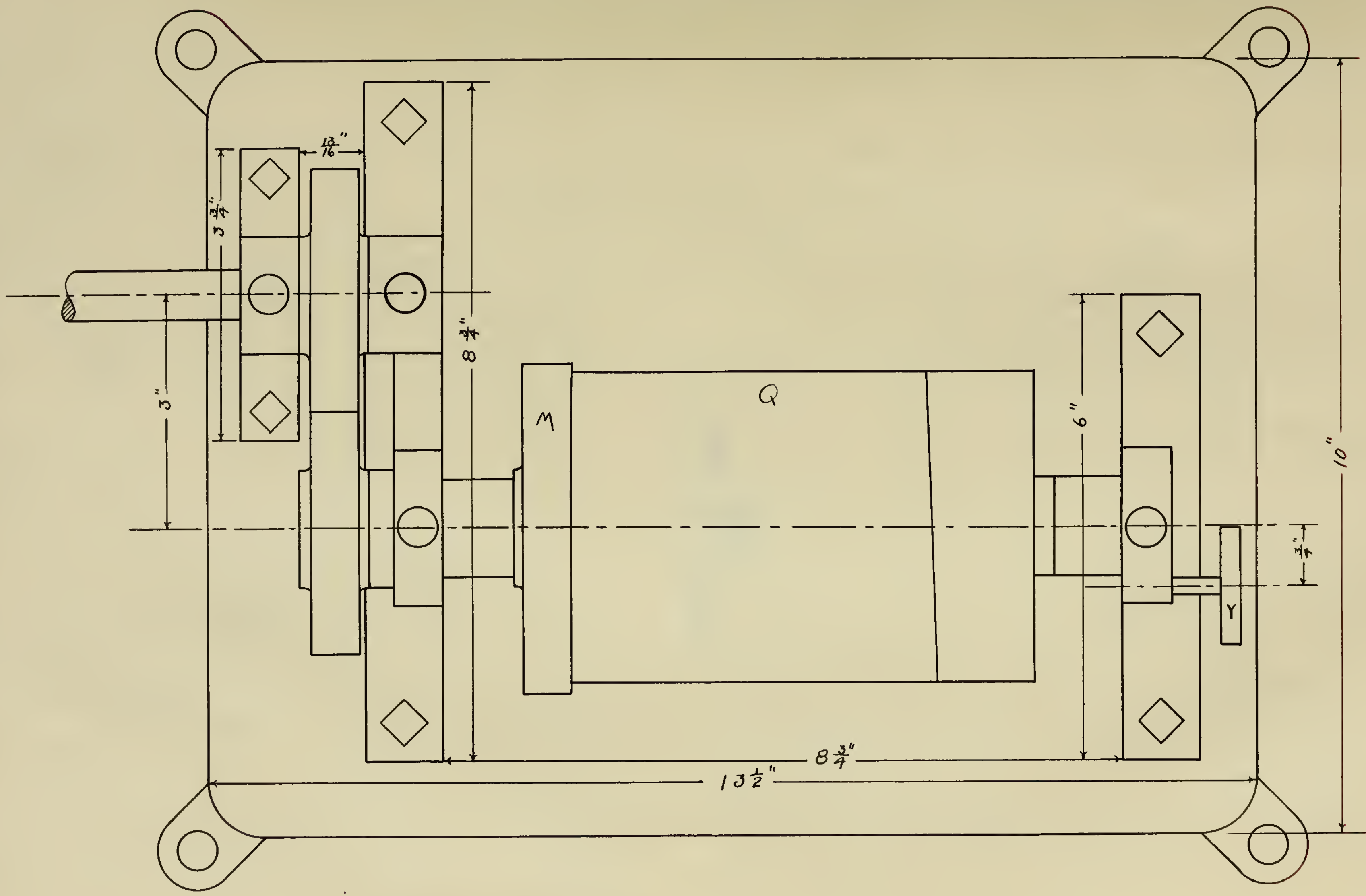


Plate I Plan View Carriage Removed

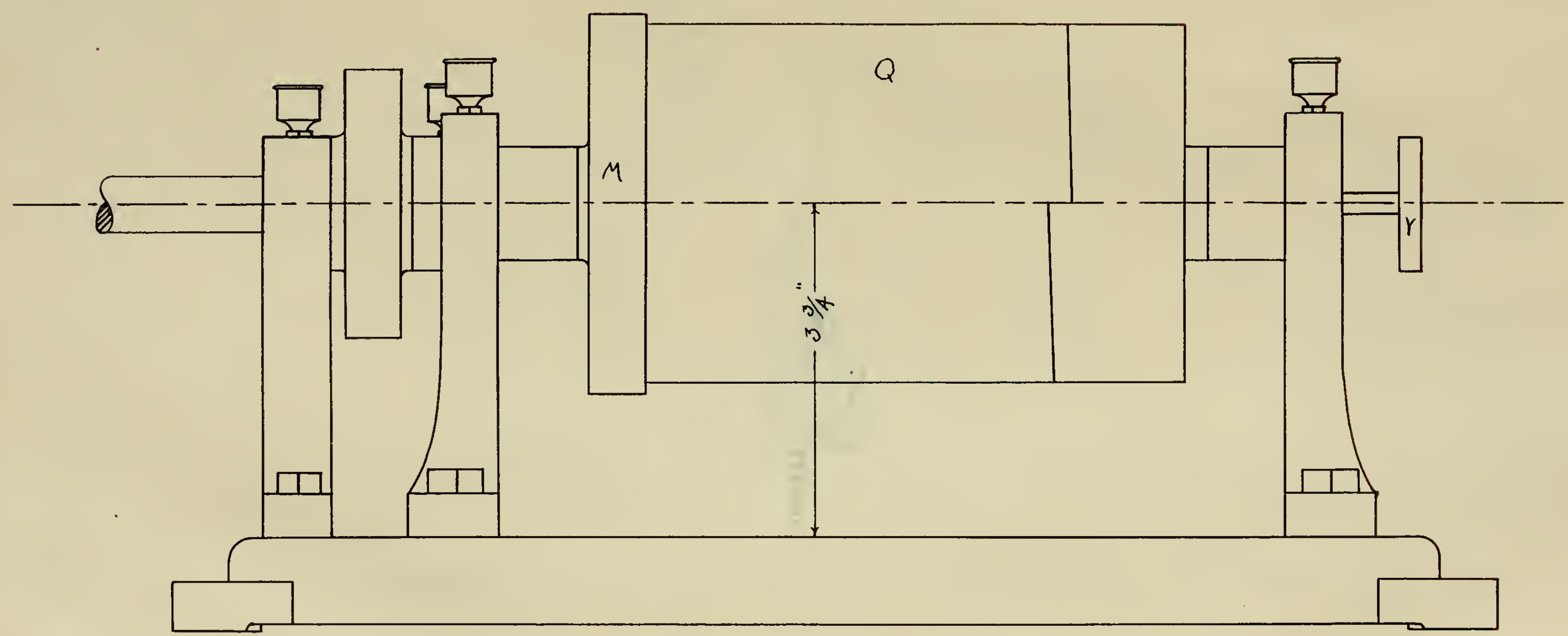


Plate II Side Elevation

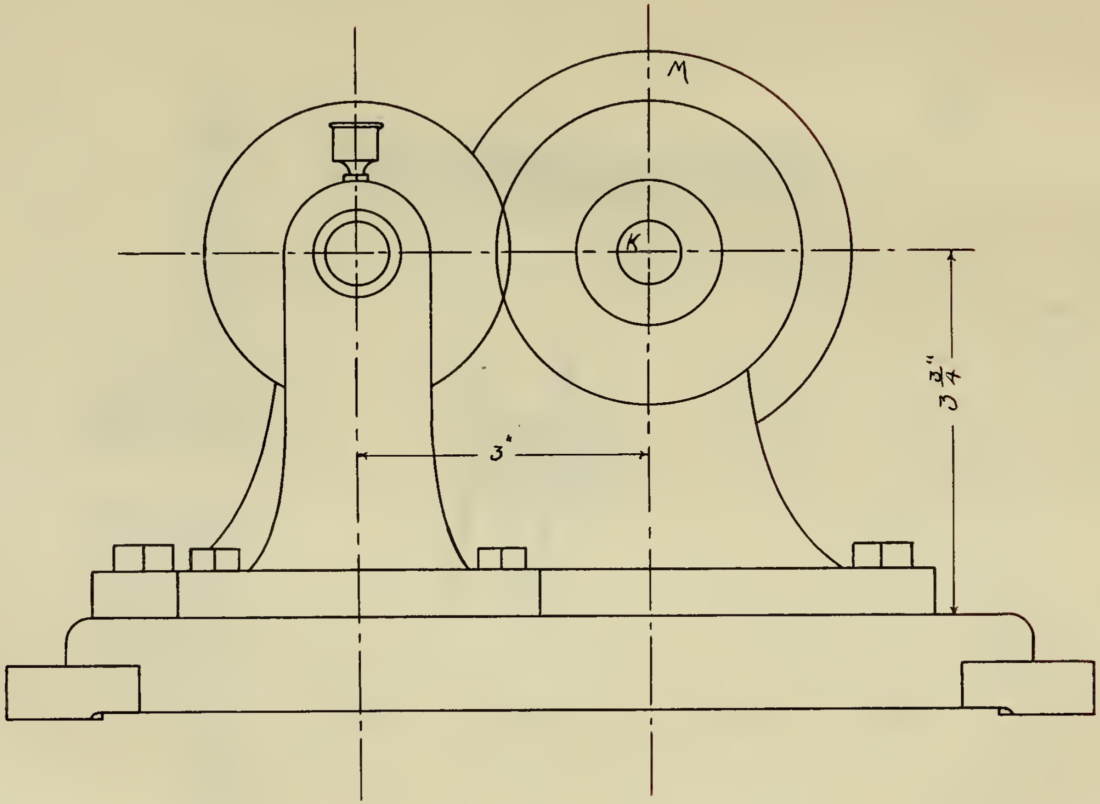


Plate III End View

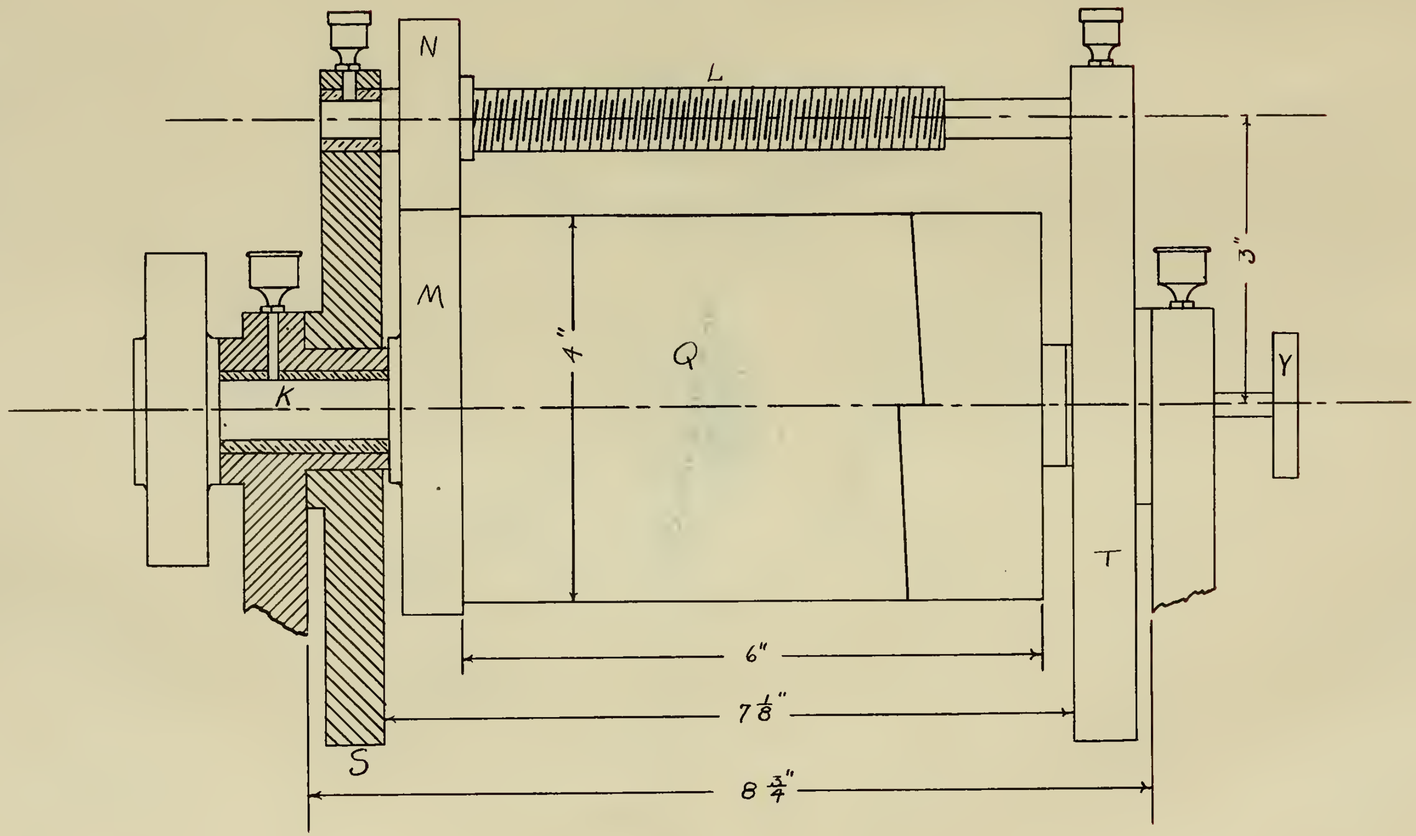


Plate IV Details of Carriage Frame

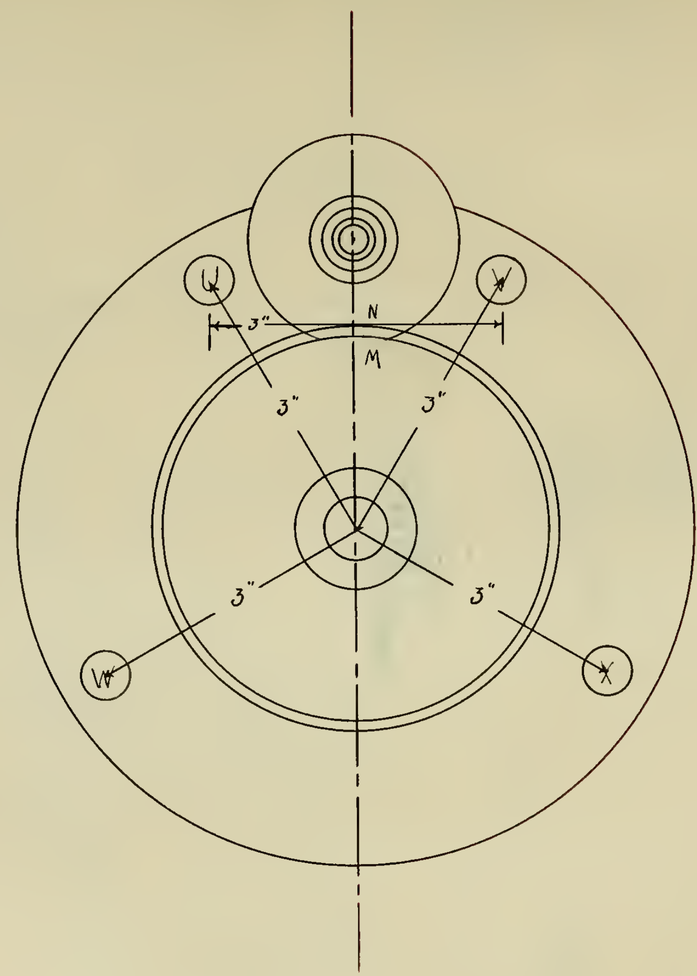
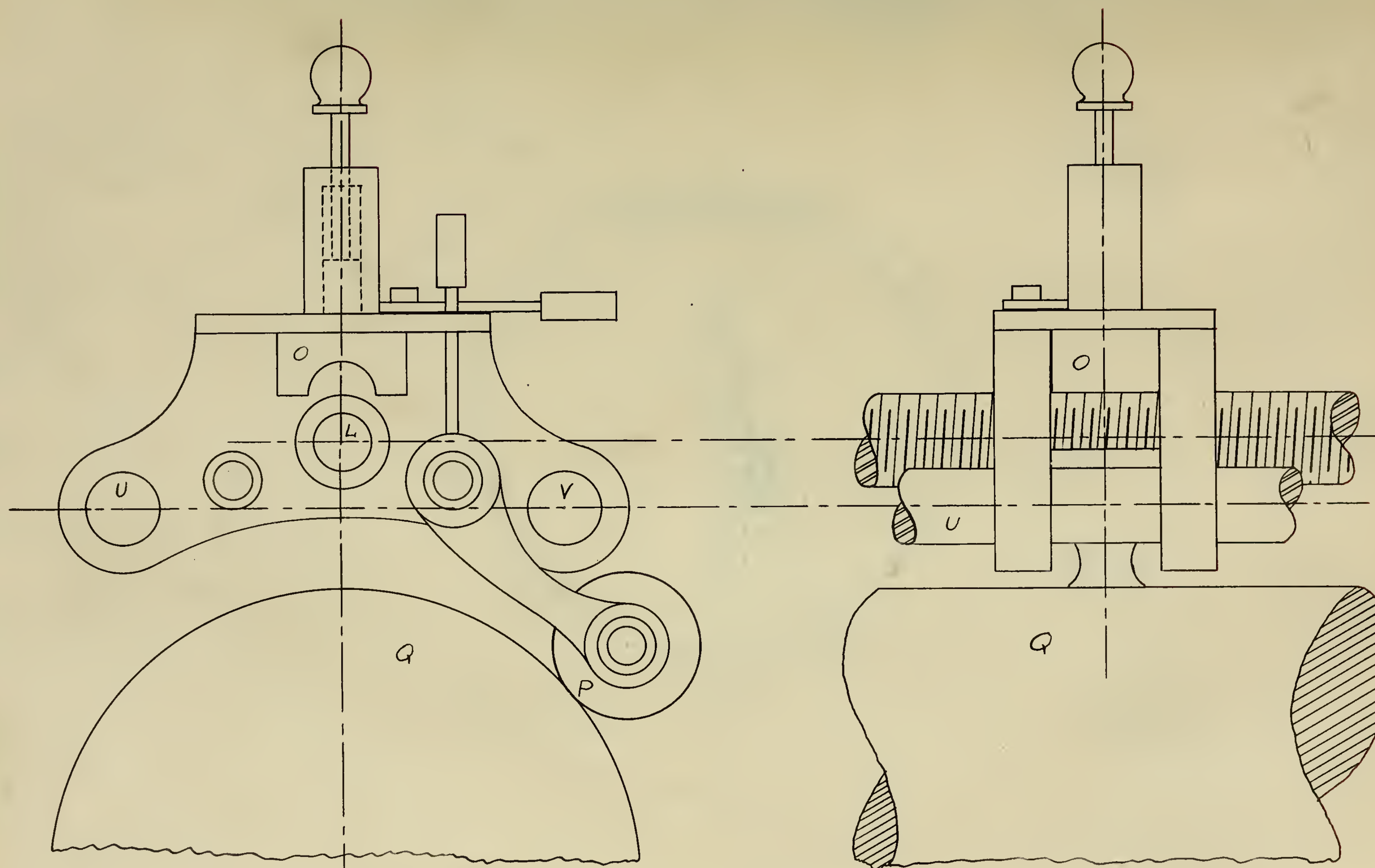


Plate V End View of Carriage Frame One Disk Removed



One Side Plate Removed

Plate VI

Carriage

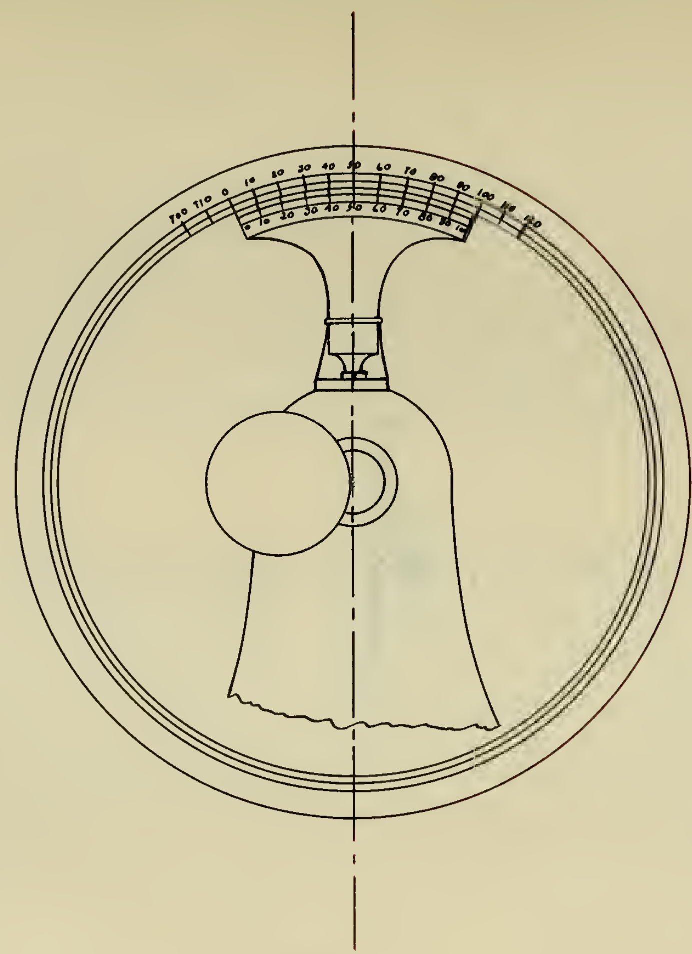


Plate VII Vernier for Angular Measurement

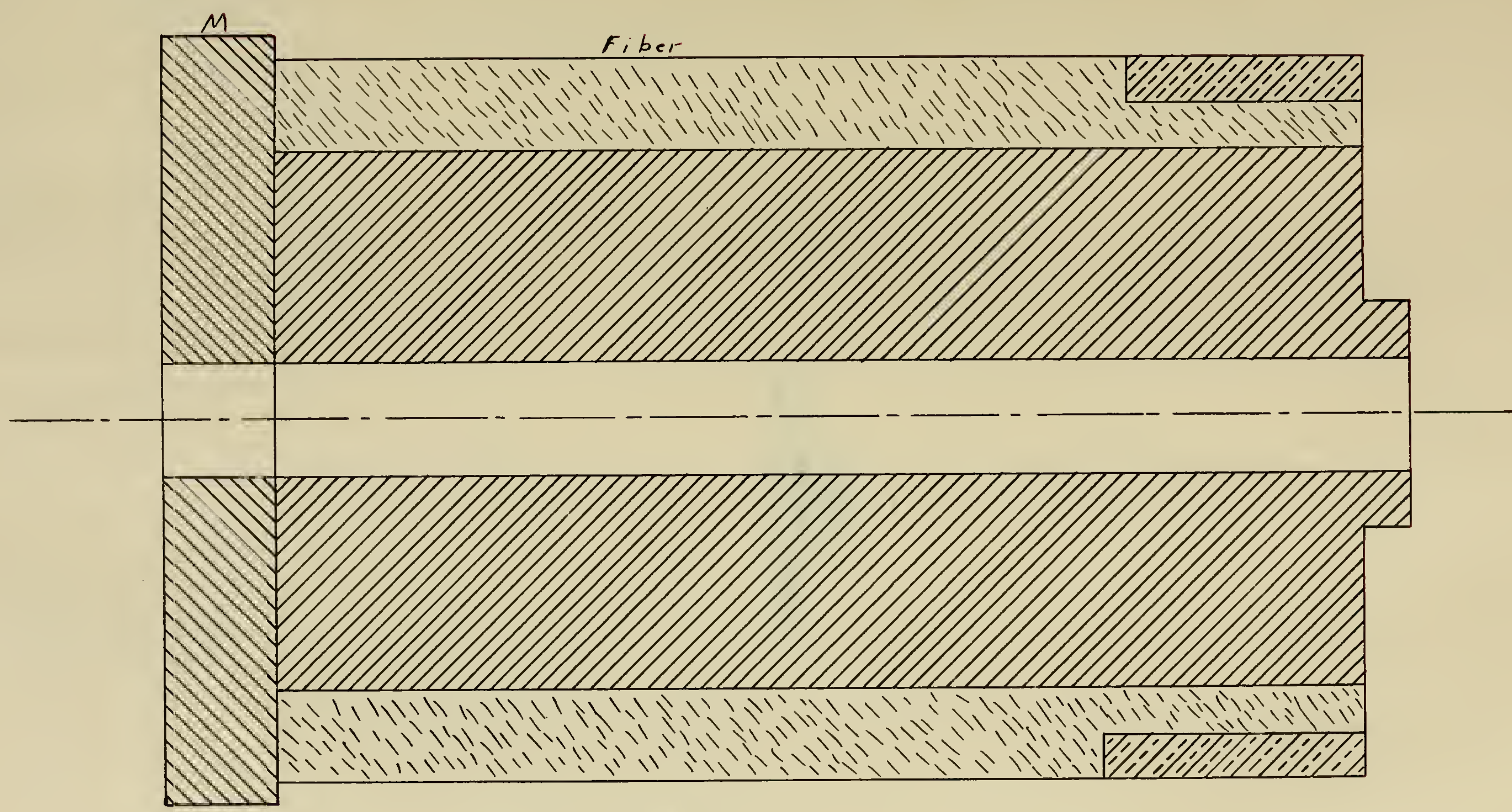


Plate VIII Cross Section of Drum